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**WORK DONE IN THE SOVIET UNION ON HIGH-VOLTAGE
LONG-DISTANCE D.C. POWER TRANSMISSION**

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The work conducted in the Soviet Union on high-voltage d.c. power transmission is based on the fact that this type of transmission may be quite effective from the technical as well as the economical standpoint in several cases as power systems continue to grow and become all the more interconnected.

Design estimates that have been made show that direct current is quite economical wherever it is necessary to transmit large blocks of power over distances of 1000 km and more. It turns out that the transmission of energy along conductors of a transmission line may favorably compete under certain conditions with the transportation of coal over railways or with the transportation of natural gas over pipe lines because of the use of direct current.

Direct current opens up new technical possibilities that are important from the operating standpoint of consolidated power pool systems and, therefore, it may be more advantageous and expedient to use direct current not only in the case of long-distance transmission, but also for inter-system tie lines of comparatively short length.

Direct current is indispensable whenever it is necessary to lay cable lines for power transmission and, in particular, for crossing over long water routes (e.g. in Sweden power is transmitted in this way to the Island of Goteland; a tie of this kind between the power systems of England and France is being designed.)

Inroads are being made at present by scientific research and experimental design projects so that the technical and economic benefits of d.c. transmission may be realized in the nearest future. It is very important that the results of many of these projects have already been put into practice, passing their check-up in operation on the experimental-commercial d.c. transmission line from Kashira to Moscow. (Ref. 1)

At present preliminary work is being carried out in the Soviet Union for the construction of a d.c. transmission line from the Stalingrad hydro-electric station to the Donbas. (Ref. 2 and 3). This line will be a component link in the Consolidated Power Pool System for the European part of the Soviet Union. The parameters of this line (transfer capacity - 750 MW, voltage - ± 400 kV, length of overhead line - about 500 km) place it in one group with the most recent three-phase extra-high-voltage high-capacity a.c. transmission systems. It may be considered that the problem of d.c. power transmission will be essentially solved by constructing the Stalingrad-Donbas line and putting it into commercial operation. The experience that will be gained in constructing and operating this transmission line will enable us to employ longer d.c. lines with larger transfer capacities more confidently. This will be required when the Consolidated Power Pool System for the entire Soviet Union will be created.

The Kashira-Moscow transmission line, which was put into service at the end of 1950, consists of two terminal converter sub-stations and 112 km of underground d.c. cable line between them.

Normally power is transmitted from Kashira (where it is generated at a thermal power plant) to Moscow (where it flows into a 110 kV network). At times, for

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experimental purposes power was transmitted in the opposite direction. The sub-station equipment permits 200 kV d.c. and 150 A d.c. to be obtained and, therefore, 30 MW is usually transmitted over the cable at 200 kV.

The Kashira-Moscow transmission line has already been connected up in several schemes and subjected to various operating conditions. Moreover, experimental studies of all kinds have been already carried out on a large scale. As a result, measures as well as devices were developed and put into operation, thereby improving the reliability of transmission considerably. Finally, a great deal of experience has been gathered, which is now being used in designing and developing the equipment for the Stalingrad-Donbas transmission line, and also in drawing up prospective plans for further use of d.c. transmission.

During the first few years of operation of the transmission system, one bridge was used for converting the current at each sub-station. There were three mercury-pool tubes (rectifiers) connected in series in each arm of this bridge. Starting with 1955 other converter schemes were experimented with. At one time a single bridge was in operation at each of the sub-stations, having one tube in each arm. The d.c. voltage in this case was reduced at first to 80 kV, and afterwards raised to 100 kV (instead of 200 kV when three tubes were in each arm). The operation of the bridge was checked with two tubes connected in each arm. Of recently, the scheme at the Moscow sub-station, which is usually subjected to inverter duty, consists of two bridges connected in series. There is only one tube connected in the arm of the first bridge, while there are two in the arms of the second bridge which operates at a higher voltage. The sub-station at Kashira, as previously, works with three tubes in the bridge arms.

The operating experience with converter schemes having one, two, or three tubes in the bridge arms which was gathered from the Kashira-Moscow transmission line indicated that series connection of the tubes in itself does not give any substantial effect as concerns reliability of the scheme in operation. The great expectations that were earlier held with regard to this connection did not materialize in practice. (Ref. 4). It was discovered, in addition, that the series connection of several tubes has some drawbacks. For example, if one tube should not ignite, the full direct voltage of the bridge arm is applied to it, while a higher back voltage appears across the other tubes. (Ref. 5).

Changing over from the scheme with one bridge to the scheme with two series connected bridges at the inverter station results in better transient performance when one of the tubes breaks down, and also in better operating reliability of the transmission line as a whole. The current surges and voltage fluctuations on the cable line during transients were greatly reduced because of this change in the scheme. If individual tubes did not ignite for a short time, the operation of the inverter sub-station was no longer endangered. (Ref. 5).

Extra-high-capacity d.c. systems may require parallel or series-parallel connection of the tubes. Therefore, a series-parallel connection of six tubes in one arm of the bridge was made and studied (three tubes were connected in series in the other arms of the bridge). Experimental results and operation confirmed the merits of this connection, namely, insensitivity of the converter scheme to lapses in the ignition of individual tubes. At the same time, some new phenomena were discovered which do not take place with parallel connection of the mercury-pool tubes in low-voltage circuits. The unpleasant consequences of these phenomena were liquidated by suppressing the high-frequency oscillations that arose when the tubes ignited. (Ref. 6).

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While making adjustments on the Kashira-Moscow line for normal operation, it was discovered that certain oscillatory processes, which arise during transient conditions, may cause dangerous overvoltages. One such process, for example, is the voltage oscillations that arise between the poles of the sub-station after the transmission scheme has been deenergized, and the cable is still under voltage. By installing appropriate damping devices in the scheme, which consist of resistors and capacitors, these oscillatory processes can be suppressed and the overvoltages associated with them liquidated.

At first the transmission was unstable in operation, and was frequently interrupted, primarily due to the instability of the mercury-pool tubes. Measures were taken along two lines to improve the reliability of the transmission; a) to improve the tubes themselves, and b) to lighten their duty in the scheme.

The tubes themselves were improved during their periodic repairs when various changes in design were made; also, their process of manufacture and high-voltage trial operation was brought up to date. Some of these tubes were replaced by newly manufactured ones of better design.

The duty of the tubes in the circuit was lightened by the introduction of appropriate damping devices and high-frequency reactors. They reduced the rate of rise of the back voltage and the magnitude of the current surge at the instant the tube ignited. Alongside of lightening the duty of the tubes when they ignite, the high-frequency reactors connected in the plate circuit of each tube enabled the radiation to be reduced and the radio interference to be brought down to a tolerable level.

Measures improving grid control as well as automatic control and protection played a positive role in the establishment of normal, stable operation of the transmission system. Among these measures, special attention should be given to the positive experience gained from the use of automatic reclosing by means of grid control. This enabled the pause in power transmission to be reduced to a minimum (0.1 to 0.2 seconds) after short-time phenomena such as arc-back took place.

The experience gathered from the operation of the d.c. cable line is of great interest. This line consists of two single-conductor cables laid alongside of each other in one trench. They have an aluminum conductor 150 mm^2 in cross-section, a lead sheath and paper insulation 12 mm thick, which is impregnated with an oil-rosin compound. At first the transmission worked without delay on the d.c. side. Under these conditions both cables were at a voltage of $\pm 100 \text{ kV}$. For the past 4-5 years the transmission system has been working with one of the d.c. poles grounded and therefore, 200 kV is applied to the ungrounded cable (the maximum potential gradient is 31 kV/mm).

In speaking of the operating experience with this cable line, it should be noted that cable of different firms are used. The best results were obtained with cables from the firm KWO (Germany) and from the works "Mos cable" (U.S.S.R.), which were laid out along a section of 30 km. There was not even a single fault on this section during the entire operating period. Tests in 1957 on pieces of cut out cable and also on various couplings indicated that electrical strength was the same as when the cable line had been laid in 1950.

For a long time the Kashira-Moscow transmission line has been operating according to the "conductor-ground" scheme. Current flows in one direction through the ground between two special ground rods in the form of iron tubes pounded right into the soil. Studies that were carried out and also operating experience indicate that in the case of direct current it is quite permissible to use the ground as the return conductor.

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Protective measures may be required only on underground metal structures that are located comparatively near the ground rods (within a radius of 5 to 10 km).

One of the existing three-phase 110 kV overhead lines running from Kashira to Moscow was used several times in an experiment on transmission. Direct current was transmitted over two line conductors at a voltage of ± 100 kV, and also over the "conductor-ground" scheme at a voltage of 100 and 200 kV. The insulation of the three-phase 110 kV line withstands quite reliably the d.c. voltage of 110 kV. At 200 kV there were cases where the insulator string flashed over during bad weather. Tests on the overhead line were made to single out the characteristics of transient and to check the damping devices limiting overvoltages.

From the above survey, which is by far incomplete, of work carried out on the Kashira-Moscow transmission system, it is quite evident that the improvements made and the operating experience gathered are of extreme importance.

Further developments in techniques of d.c. power transmission. Work on the development of d.c. power transmission in the Soviet Union is carried out at the Scientific Research Institute on Direct Current of the Ministry of Power Stations, the Lenin All-Union Electrotechnical Institute, the Power Institute of the Academy of Sciences, the Institute of the Cable Industry, and at design departments of several large electrical plants. Several departments of our educational institutes participate in the solution of some questions in the general problem. D.c. transmission lines are being designed at the project institutes "Teploelectroproject" and "Hydroproject" in conjunction with the Direct Current Institute.

Scientific investigations and developments in design are coordinated by appropriately distributing the different work, by the organization of information exchange, and by joint conferences. All work required for creating the d.c. transmission line Stalingrad-Donbas is coordinated by the Ministry of Power Stations and is carried out in accordance with a general plan. Research work on some topics is carried out jointly by several organizations in accordance with general programs. Most frequently it consists of large-scale experimental investigations carried out on the transmission line Kashira-Moscow. The results of work after its conclusion or at intermediate stages are generally discussed at meetings of Scientific and Technical Councils at the Institutes. Moreover, other organizations engaged in the solution of the general problem always have their representatives participating in the work of the Council of the given Institute.

Work on the further development of techniques for d.c. power transmission is being carried out along the following main lines:

1 - Schemes for the d.c. transmission line are being developed as well as for its junction with a.c. systems and large power stations. Special attention is paid at present to questions of intermediate power take-off from d.c. lines by creating the necessary taps and also of intermediate sub-stations. The solution to the problem of directing power transmitted over an extra-high-capacity d.c. line to two or even more points (instead of one) at the receiving system is part of the problem stated above. Preliminary solutions to these problems indicate that difficulties encountered in protecting and automatically controlling d.c. transmission systems with intermediate sub-stations may be overcome. Moreover, in the more complicated case good use may be made of the possibilities of grid control of the tubes.

2 - Converter schemes are being worked out, the theory of current conversion is being developed, and steady-state and especially transient and fault conditions in the operation of the converter sub-stations of the d.c. transmission system are being studied. Special attention is paid to particular questions which arise in the event of cascade

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connection of several bridges on the d.c. side so as to obtain a sufficiently high voltage, e.g. questions of uniform voltage distribution among the bridges (after current has ceased to flow in the circuit), internal overvoltage protection, damping oscillatory processes, reduction of the upper harmonic content by improving the phase of the conversion, reduction of the mutual influence of the bridges, etc. Efforts are also being made along these lines to create the best possible schemes and means for compensating the reactive power consumed by the inverter sub-station.

3 - Studies are being conducted on joint operation of the d.c. transmission line with an a.c. system connected to it. Here we deal with questions such as how abnormal conditions in the transmission system influence operation of the receiving system, and also how fault conditions in the receiving system influence operation of the inverter sub-station. Ways are sought for using d.c. transmission lines with their high-speed grid control to improve the transient stability of adjacent systems and of long-distance transmission lines.

4 - Studies are being conducted on the performance of the insulator string as well as on the external and internal insulation of the equipment and apparatus when subjected to a large d.c. voltage, and also a d.c. voltage with an a.c. component of varying frequency superimposed. The results of these studies will lead to more rational design of the insulation for d.c. overhead lines, high-voltage d.c. cables, power transformers, capacitors, d.c. instrument transformers and other equipment for converter sub-stations. Research on corona discharge at a large d.c. voltage related to this line of investigation is also being carried out.

5 - High-voltage, high-capacity mercury-pool tubes, the main element in the converter sub-station, are being developed. The design of these tubes is based on the results of extensive research of different physical phenomena, on the performance of sample tubes which are tested at special set-ups and also under actual operating conditions on the Kashira-Moscow transmission line. The tube designed in the Soviet Union has only one plate no matter what its capacity in contradistinction to that of the Swedish firm A.S.E.A., in which the number of parallelly connected plates increases with the tube capacity. (Ref. 12).

6 - The following equipment for the converter sub-stations is being designed; power transformers, isolating and instrument transformers, capacitors, lightning arresters, disconnecting switches for shunting and other special apparatus. Work is being carried out on creating high-voltage d.c. power cables, which is also associated with this line of activity.

7 - Special automatic devices are being developed that generate pulses for the grid control and for the automatic control and protection of the d.c. transmission line. These devices substantially influence the performance of the transmission system during normal as well as transient and fault conditions. Therefore, they are developed on the basis of all-round studies of these operating conditions.

Many of the investigations listed above are carried out on laboratory installations, which model the real d.c. transmission system of the future to a certain scale. The parasitic parameters of real high-voltage installations, as well as the main parameters may be modelled at these installations. This enables low-frequency as well as high-frequency processes (up to hundreds of kc) to be investigated on these models. Models are a powerful tool in the hands of a research worker and a designer of new devices and apparatus.

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The Stalingrad-Donbas transmission system will be a great advance in the development and practical application of d.c. power transmission techniques. This transmission system (Fig. 2) contains an overhead line of about 500km long and two convertor sub-stations, one of which is located in the building of the Stalingrad hydro-electric station, and the other in the Donbas. The voltage between conductors is 800 kV (+ 400 kV relative to ground) and the rated transfer capacity is 750 MW. Provision is made for power transmission in both directions.

Eight generators are allotted at the Stalingrad hydro-electric station for the transmission of direct current. They are connected through power transformers to the rectifier bridges and 220 kV buses. The power generated by these eight units may be directed in part over the d.c. line to the Donbas and in part to the 220 kV buses. D.c. transmission coming from Donbas is directed to the 220 kV buses, and from there it is distributed together with the power from all of the generators at the station.

The convertor sub-station in the Donbas links the d.c. line with the 220 kV a.c. network there. Power is transmitted or received through several lines that run out from the 220 kV buses.

The mid-points on the d.c. side at both convertor sub-stations are connected to special ground rods that are designed for continuous flow of the rated current of the transmission line. This grounding divides the transmission system into independent halves, and enables one half to remain in operation when the other one gets out of commission. In this case the current flows through the ground.

There are eight identical bridges connected in series at each converter sub-station. With this number of bridges any possible disruptions in the operation of one of them will little influence the operation of the other bridges and of the transmission system as a whole. In case one of the bridges is shunted, the remaining seven ensure the latter within limits.

In order to reduce the upper harmonic content on the d.c. side as well as on the a.c. side, the windings of each transformer connected to the bridges are connected differently, in wye or delta. As a result, twelve-phase conversion is obtained.

All the reactive power required at the Donbas substation is supplied by three banks of capacitors (having a total of 400 MVARs), which are connected to the 220 kV buses, and at the Stalingrad sub-station by the water-wheel generators.

Some auxiliary elements are installed in the scheme of the converter sub-station so as to alleviate the duty of the main equipment, and primarily of the tubes, during steady-state as well as transient conditions. Some of these elements are as follows:

capacitors and resistors limiting the magnitude and rate of rise of the back voltage;

plate reactors limiting the discharge current of the stray capacitances in the circuit through the tube at the instant it ignites;

capacitors and resistors for uniformly distributing the voltage between the bridges and also for damping the voltage oscillations after the circuit is deenergized;

special arresters serving as protection against internal overvoltages.

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A shunting tube and a disconnecting switch are connected in parallel with every bridge between its poles. The shunting tube serves as protection during arc backs and break downs in the tubes as well as other short-time disruptions in the operation of the bridge. The shunting disconnecting switch is used for cutting out the bridge for a long time, for example, when replacing a tube.

The convertor sub-stations use single-plate tubes for 900 A, 130 kV (Fig. 2 and 3). These tubes are six times more powerful than the tubes used in the Kashira-Moscow transmission system. Air may be pumped out from the tubes. The lower part of the tube of metal is cooled by circulating transformer oil, while the upper part of the tube containing the plate has natural air cooling. The tube is 3.5 meters high and weighs about 2 tons (Ref. 13).

The power transformers are single phase and come in two insulation classes. Transformers closer to the grounded mid-point in the circuit from the potential standpoint are subjected to a test voltage of 570 kV, while the other transformers are subjected to a test voltage of 1000 kV.

The d.c. overhead line is constructed with T-shaped steel towers (Fig. 4). Each line pole consists of two aluminum-steel conductors having a cross-section of 712 mm^2 (the aluminum part), which are diverged along the horizontal by 400 mm from each other. The line is protected against direct lightning strokes by a single steel ground wire having a protection angle of 30° . When designing the d.c. line, it was possible to reduce somewhat the requirements levied on the lightning protection because of the advantages of the grid protection.

The length of the insulator string and the air insulation clearances were selected on the basis of limiting internal overvoltages to a value not greater than 1.7 of the rated working voltage. In order that voltage oscillations on the line do not exceed this value during transients, special transverse damping circuits of resistors and capacitors are connected at the ends of the line.

It should be noted that the length of the insulator string could not be made shorter by even further limiting the magnitude of these internal voltages of short duration (amounting to tenths of a second), since shorter insulator strings would flash over during bad weather when rated voltage is applied continuously.

The overvoltages arising on the line will be applied to the sub-station equipment, also, in the event current stops flowing in the circuit. Therefore, the maximum magnitude of the overvoltage given above (1.7) is relevant not only for the line, but also for determining the requirements of the insulation of all of the sub-station equipment.

A system of automatic regulators is used to attain the most economical operation for the transmission system under normal conditions and to secure its stability during various kinds of transient conditions.

A given transfer capacity is maintained automatically regardless of the voltage fluctuations on the 220 kV buses of both substations. For this purpose regulating transformers (Fig. 1) are used and voltage regulation is employed on the water-wheel generators. If it should be necessary to change the direction of power flow over the transmission line, coordinated switching in the grid control devices is carried out at both sub-stations.

When transmitting power to the Donbas, frequency control is provided at the receiving end by appropriately varying the transmitted power.

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The grid protection worked out for the transmission system is quick acting. Therefore, in the majority of cases it should prevent the fault from developing, protect the equipment from being damaged, and enable normal operation of the entire transmission system to be restored after some fraction of a second.

The use of direct current for transmission from Stalingrad to the Donbas over a distance of 500 km does not result in any economical benefits as concerns first costs, losses and the cost of transmitting one kilowatt-hour. The technical and economic characteristics of the ± 400 kV d.c. scheme and of the 400 kV a.c. scheme are about the same. All of the gain obtained by using d.c. in the line part of the transmission system (the line is 1.6 times cheaper, and its losses are twice as less) is completely expended in this case in the more intricate terminal sub-stations. However, the use of direct current for such an inter-system tie has definite advantages in operation; for example:

the frequency may be controlled independently in the two a.c. systems that are linked;

the power transmitted may be controlled according to a pre-established program;

faults in one system are felt much weaker in the other system;

the single-circuit d.c. line is much more reliable because of the possibility of using the ground as the return conductor, and because the automatic reclosing cycle is limited to its minimum value.

The construction and operation of the Stalingrad-Donbas transmission system will permit the necessary experience to be gathered so that within the next ten years we may begin to construct d.c. transmission lines at ± 600 to ± 700 kV having a transfer capacity of 2 to 4 million kW per circuit. These lines will serve to transmit large blocks of cheap power from the regions of central Siberia to the Urals (where fuel is expensive), that is, over a distance of 2000 to 2500 km. The use of direct current for such transmission systems will have a great effect on the national economy.

The effect expected from using direct current for power transmission over long distances. By making use of design material that has already been compiled, it is possible at present to compare from the economic standpoint transmission by means of direct current with that by means of three-phase alternating current, and also with the transportation of coal over the railways and of natural gas over pipe lines (all pertaining to the conditions of the Soviet Union).

When comparing the a.c. and d.c. schemes for a definite case of power transmission, the optimal solution to the problem using each of these schemes should be taken. By that we mean the optimal values of the line voltage, the conductor cross-section, etc.

Calculations made for many different transmission systems with overhead lines indicate that the relationship between the optimal voltages is usually the following:

$\pm U = U_{\sim}$, where U is the voltage of one line pole to ground in the d.c. scheme, and U_{\sim} is the r.m.s. value of the line-to-line voltage in the a.c. scheme. The total conductor cross-section selected in each scheme on the basis of the economical current density is 1.5 to 2.5 times smaller for d.c. than for a.c. When these relationships are observed, the d.c. line is always less expensive and has smaller losses.

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The characteristics of two concrete transmission lines (a d.c. line and an a.c. line) are given below in the table. (Ref. 14).

TABLEEconomic Comparison of D.C. and A.C. Transmission Systems

<u>No.</u>	<u>Basic Parameters</u>	<u>Transmission System 1</u>		<u>Transmission System 2</u>	
		d.c.	a.c.	d.c.	a.c.
1	Length of line, km	1000		2200	
2	Capacity, MW	1000		6000	
3	Annual energy transfer, billion kWh	7		42	
4	Voltage, kV	±500	500	±600	600
5	Number of circuits	1	1	2	3
6	Conductor cross-section per phase or pole, sq. mm.	3x712	3x712	4x712	4x712
7	Losses (%)				
	in lines	2.74	5.33	8.84	12.15
	at substations	2.70	1.44	3.20	2.19
	in compensating devices	--	0.58	--	1.40
	total	5.44	7.35	12.04	15.74
8	Cost of transmitting one kWh, kopeks	0.80	1.05	0.72	1.22

From a comparison of both schemes it follows that the use of alternating current for transmission system 1 is more expensive by 25%, while for transmission system 2 this figure rises to 98.5%. There is some discrepancy here as regards the percentage distribution of the cost of the elements for both transmission systems. This cost distribution among the various elements is given below.

	<u>Transmission System 1</u>		<u>Transmission System 2</u>	
	d.c.	a.c.	d.c.	a.c.
Lines	58.5	66.6	56.0	59.2
Sub-stations	41.5	23.0	44.0	16.6
Compensating devices	--	10.4	--	24.2
Total	100	100	100	100

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It is seen that the use of direct current is expedient economically not only when constructing extra-long-distance extra-high-capacity transmission systems (transmission system 2), which is usually not questioned, but also in the case of transmitting 1000 MW over a distance of about 1000 km (transmission system 1).

The benefits of using direct current become greater not only for an increase in the transmission distance, but also for an increase in the power transmitted. When large blocks of power are to be transmitted, the d.c. scheme has additional advantages connected with the greater transfer capacity of its line. This follows clearly from the example of transmission system 2. In the a.c. scheme three circuits have to be used instead of two as in the d.c. scheme. The a.c. line is more than twice as expensive and the losses in it are 1.4 times greater than in the d.c. case.

Calculations have been made in the U.S.S.R. comparing power transmission over conductors with the transportation of coal over the railways for various concrete cases. In certain cases when the distances involved were sufficiently large, it turned out that power transmission using direct current is economically justified rather than transporting the coal. For example, d.c. transmission from power stations working on cheap untransportable coals to the industrial districts of the Urals over a distance of 2200 km was compared with the transportation of more expensive high-calory-content coals from the Kuznets basin to the power stations in the Urals. It turned out that the first costs for erecting the d.c. transmission line are somewhat greater; however, the operating costs and the energy cost at the consumer are lower. These additional first costs will be reimbursed in the course of four to five years.

Plans exist in the Soviet Union for increasing the use of natural gas as the fuel at power stations. The following question may be asked: is it more expedient to transport gas over a long distance through pipe lines or to build power stations at the place where the gas deposits are and to transmit power over conductors? Calculations indicate that when sending 2000 to 4000 MW over a distance of 1000 km or more, the use of direct current for transmission is entailed with additional first costs as compared with the gas pipe line; however, these additional costs are reimbursed not over a long period since the operating costs in the d.c. scheme are lower. For example, when transmitting 2400 MW over 1500 km the period for reimbursement of the additional first costs in the d.c. scheme amounts to about six years.

Work done on d.c. transmission schemes and on the design of the terminal elements allow us to expect cost reductions there.

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CAPTIONS TO THE FIGURES

- Fig. 1 - Circuit diagram of the d.c. Stalingrad-Donbas transmission system.
 1 - 105 MW 13.8 kV water-wheel generators; 2,3,4 - power transformer windings;
 5 - regulating transformers; 6 - bridges; 7 - shunting tubes; 8 - shunting disconnecting switches; 9 - output devices; 10 - working ground rods; 11 - ± 400 kV d.c. overhead line; 12 - 132 MVAR, 220 kV, three-phase bank of capacitors.
- Fig. 2 - Drawing of a 130 kV, 900 A tube.
- Fig. 3 - General view of a 130 kV, 900 A tube.
- Fig. 4 - Suspension tower for the ± 400 kV, 750 MW d.c. transmission line.

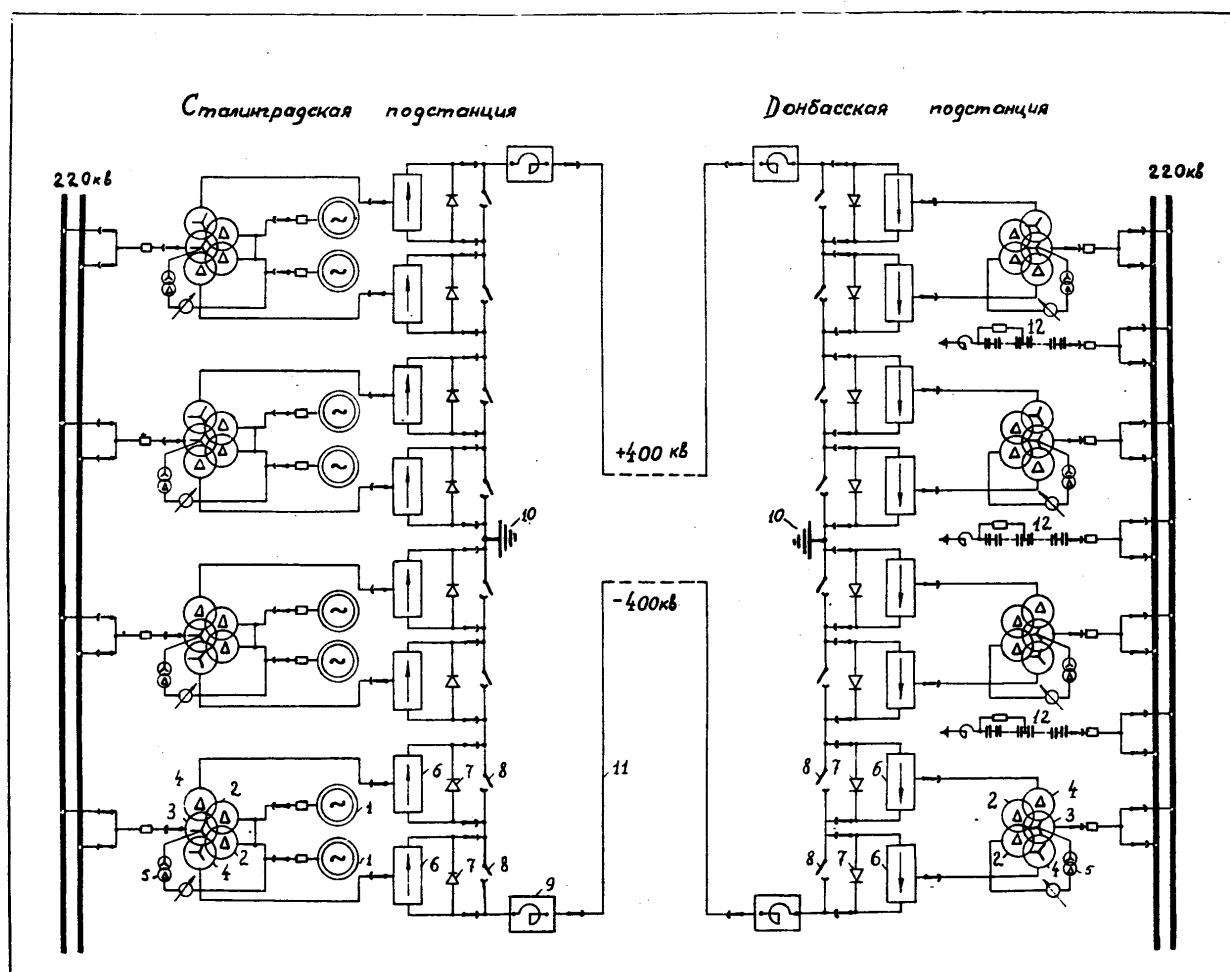
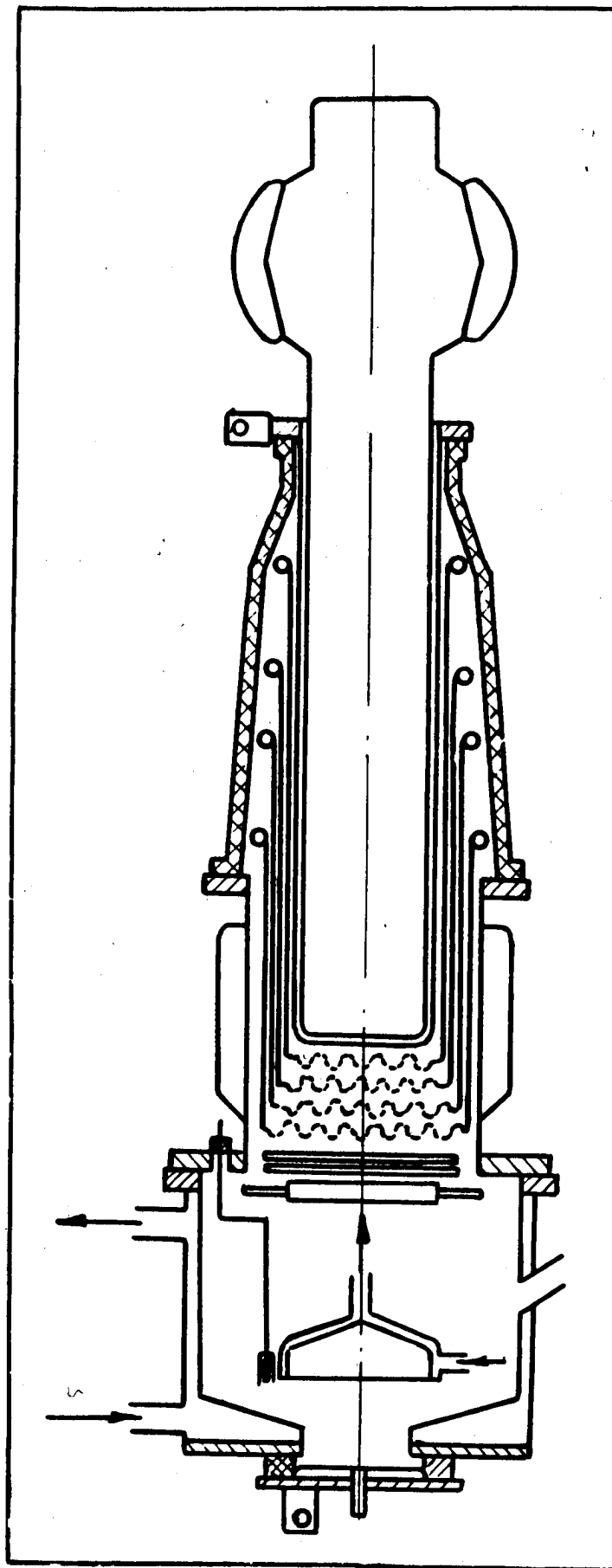


FIGURE 1



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FIGURE 2

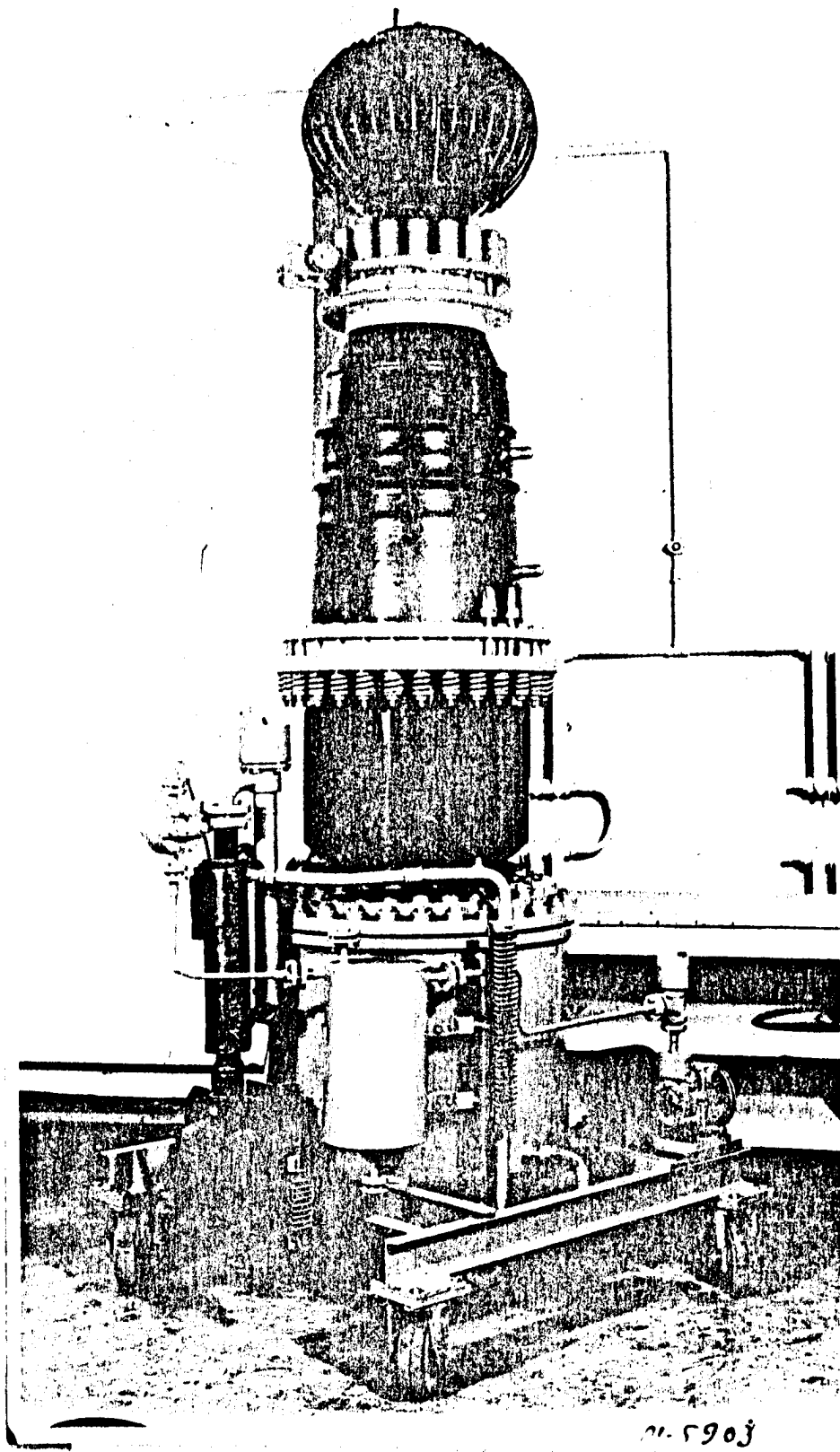


FIGURE 3

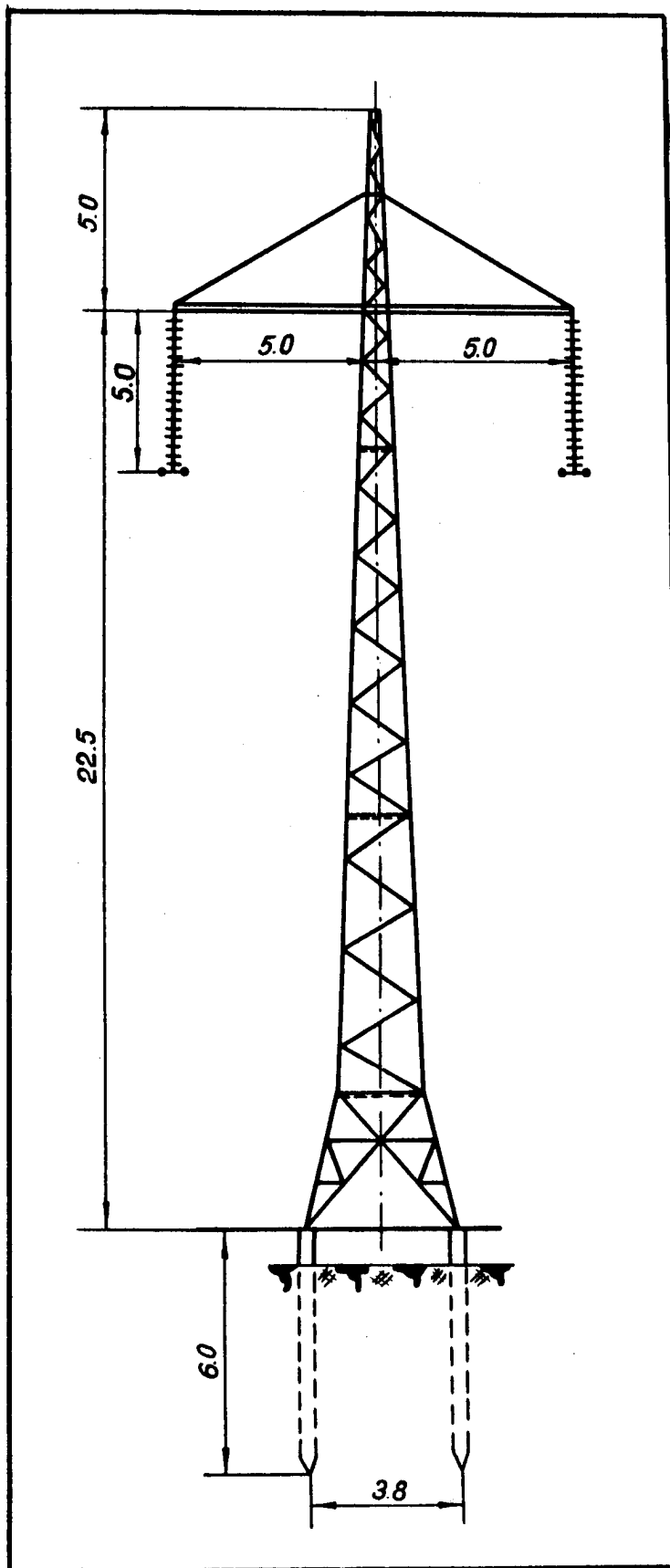


FIGURE 4

(Distances given in meters)